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A Study of Wind Turbine Blade Structure Based on Cellulose Fibers Composite Material.

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***Abstract*— in the present study, the feasibility of using the cellulosic fibers in the natural fiber reinforced polymer composites (NFC) for constructing wind turbine blade structure will be reported. To do that, it was necessary to identifies first, the principal solicitations exerted in wind turbine blades. Second, categorise the principal characteristic of cellulosic fibers compared with ordinary synthetics fibers, in the way of evaluating their principal characteristics relative to comprehensive desired measures required in wind stresses resistance. And third, report the natural fibers effects on wind blade behavior through FE simulation of the wind turbine blades made from cellulosic composite structure. To ensure the potential and competitiveness of the natural fibers in developing the sustainability of wind blades, several comparisons between fiber types commonly used was carried out. The FE results of wind turbine blade resistance to complex loading based on different types of NFC were evaluated. The resistance of the composite structure to the multi complex loading is numerically approved for the Hemp and Alpha fibers. The numerical study gives encouraging results in the sense of using NFC based on cellulosic fibers for constructing wind turbine blades.**

***Keywords*—** *Wind energy; Wind turbine blades; Cellulosic fibers; Natural Fiber Composites (NFC); FEM*

I. Introduction

For the reduction of the fossil fuel needed, many countries resort to the use of the renewable energy, in particularly, wind energy production. And this energy it will be highly expanded in the next years. Then the installation and use of large numbers of wind turbines it will be a very significant energy requirements. Then the performances of such wind turbine can be fulfilled only by using innovative, lightweight and highly durable composite materials such as natural fiber composite (NFC).

The most important parts of the wind turbines, produced from composites, particularly the wind turbine blades (WTB). The WTB are subjected to complex, combined impact, static and random cyclic loading. In order to resist to these loading over many years and hundreds of millions of loading cycles and to reduce the different types of forces, it is recommended to build the wind blades from fiber reinforced polymer composites. It is apparent that the currently available solutions for fibers reinforcement composite is the use of E-glass/epoxy composite [1]. But recently, there has been a rapid growth in research and innovation in the natural fibre composite (NFC). The uses of NFC gives important resistant to complex wind loading and are environmentally friendly and recyclable composites.

The strength and durability of wind blades are controlled by damage processes at the microlevel, in fibers, on the fiber/matrix interfaces, between plies. Also the materials with nano-engineered matrix (or sizing) and microscale (e.g., carbon fiber) reinforcement can demonstrate in some cases the up to 80% higher fracture toughness and lifetime than the neat composites [2]. For that reason in this work to evaluate the blade structure made from NFC it was necessary first to identify the blade composition and the applicable solicitation. And second identify the cellulose fibers characteristics and And then conduct the numerical test of the structure under complex load through FE simulation.

II. Wind turbine blades

A. *Principal solicitations in wind turbine blade*

Blades are the most important composite part and the highest cost component of the wind turbines. a wind turbine blades consists of two faces joined together and stiffened both by one or several integral webs linking the upper and lower parts of the blade shell or by a box spar with shell fairings [3] see Fig.1. On wind turbine blades, the flapwise load is caused by the wind pressure, and the edgewise load is caused by gravitational forces and torque load. The parts of blade which are made from different types of composite structures, are primarily designed against several solicitation and are shown in table 1.

As shown in table 1, the diverse loading that exist at several locations at the blades suggest that it could be gainful to use different composite materials according to the different zones of blades see Fig.2.

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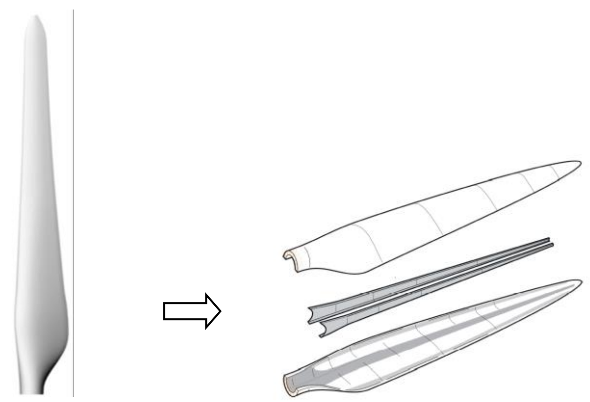
TABLE I
COMMON SOLICITATION IN BLADE

Blade parts	Structure	Solicitation needed to resist
The two external faces: The upper part of the blade shell The lower part of the blade shell	Triaxial laminates	. Edgewise bending. . Cyclic tension-tension loads. Cyclic compression -compression loads
The shear webs	Foam	Flapwise bending
The spar caps	Uniaxial laminates	Flapwise bending
The aeroshells	sandwich structure	Elastic buckling
The leading and trailing edge panels	Foam	Bending moments associated with the Gravitation loads



(a)Wind turbine blade (b) Two aeroshells and the two shear webs [2]

Fig. 1 The two aeroshells and the two shear webs of wind turbine blade

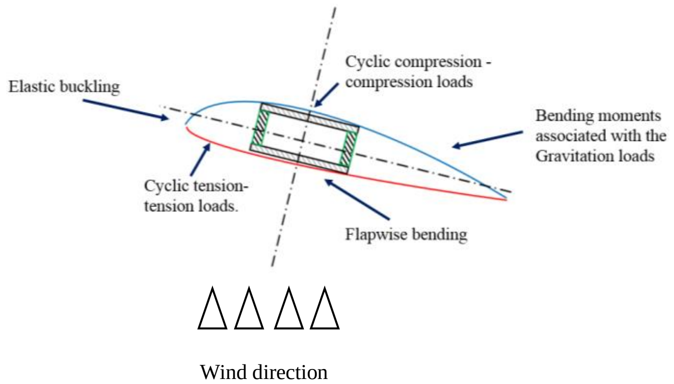
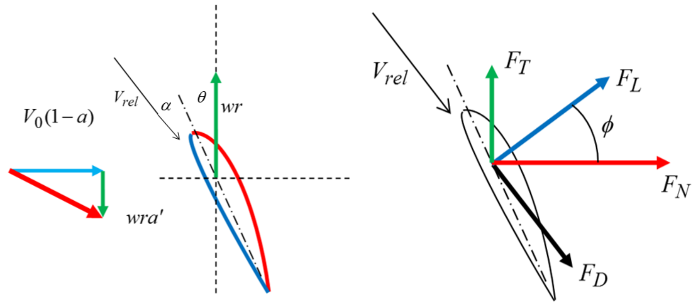


Fig. 2 Representation of the zones of the blade solicitation

B. *Load effects in wind turbine blade*

In order to make an accurate modelling of the wind turbine blades it is necessary to identify the load cases, for this study it was considered two cases of load at Normal operation and at Extreme wind loading.



(a) Induced wind velocities (b) Blade lift and drag forces/normal and tangential directions

Fig. 3 The blade induced velocity and forces

The vortex system induces on a wind turbine an induced axial velocity and an induced tangential velocity components. The induced axial velocity is specified through the axial induction factor *a* as *aVo*, where *Vo* is the undisturbed wind speed. The induced tangential velocity is in the rotor wake is specified through the tangential induction factor *a'* as 2*a'*ω *r*. Since the flow does not rotate upstream of the rotor, the tangential induced velocity in the rotor plane is thus approximately *a'*ω *r*. ω denotes the angular velocity of the rotor and *r* is the radial distance from the rotational axis. If *a* and *a'*are known, a 2-D equivalent angle of attack could be found based to the work of Martin O. L. Hansen [4] as:

$$Va = (1-a)\ Vo \quad (1)$$

$$Vrot = (1+a')\ \omega\ r \quad (2)$$

The relative wind speed V_{rel} has direction $\phi = \alpha + \theta$

Where:

θ : The local twist angle of blade
α : The local angle of attack

$$V_{rel}\cos\phi = \omega r(1+a') \quad (3)$$

$$\tan\phi = \frac{(1-a)V_0}{(1+a')\omega r} \quad (4)$$

- The lift and drag normal and tangential forces are:

$$F_N = F_L\cos\phi + F_D\sin\phi \quad (5)$$

$$F_T = F_L\sin\phi - F_D\cos\phi \quad (6)$$

- The normal and tangential force coefficients are:

$$C_N = C_L\cos\phi + C_D\sin\phi \quad (7)$$

$$C_T = C_L\sin\phi - C_D\cos\phi \quad (8)$$

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The uses of the momentum theory to equate the momentum changes in the air flowing through the turbine with the forces acting upon the blades, gives for normal forces:

$$4\pi r a = \frac{1}{2} B \frac{(1-a)}{\sin^2 \phi} c C_N \qquad (9)$$

Hence: $$\frac{4\sin^2\phi}{\sigma C_N} a = 1 - a \qquad (10)$$

Where:

σ is the rotor solidity: $\sigma(r) = \frac{c(r)B}{2\pi r}$

B: Number of blades

- the momentum theory for Tangential forces gives:

$$4\pi r a' = \frac{1}{2} B \frac{(1+a')}{\sin\phi\cos\phi} c C_T \qquad (11)$$

-

Hence:

$$\frac{4\sin\phi\cos\phi}{\sigma C_T} a' = 1 + a' \qquad (12)$$

These equations can be rearranged to give the axial and angular induction factors as a function of the flow angle.

Axial induction factor: $$a = \frac{1}{\frac{4\sin^2\phi}{\sigma C_N} + 1}$$

(13)

Angular induction factor:

$$a' = \frac{1}{\frac{4\sin\phi\cos\phi}{\sigma C_T} - 1} \qquad (14)$$

The normal force F_N causes a "flapwise" bending moment at the root of the blade.

$$M_N = \int_{r_{min}}^{R} F_N (r - r_{min}) dr \qquad (15)$$

The tangential force F_T causes a tangential bending moment at the root of the blade.

$$M_T = \int_{r_{min}}^{R} F_T (r - r_{min}) dr \qquad (16)$$

If neglect the relatively small twist of the blade cross section and assume that these bending moments are aligned with the principal axes of the blade structural cross section.

The maximum tensile stress due to aerodynamic loading is therefore given by:

$$\sigma_{max,aero} = \frac{M_N}{I_{TT}} \frac{d_o}{2} + \frac{M_T}{I_{NN}} \frac{b}{2} \qquad (17)$$

Consider equilibrium of element of blade:

$$\frac{dF_c}{dr} = -m(r)\omega^2 r \qquad (18)$$

$$\sigma_c = \frac{F_c(r)}{A(r)} \qquad (19)$$

- Self-Weight loading

The bending moment at the blade root due to self-weight loading can dominate the stresses at the blade root. Because the turbine is rotating the bending moment is a cyclic load with a frequency of $f = \omega / 2\pi$. The maximum self-weight bending moment occurs when a blade is horizontal.

Bending moment at root of blade due to self-weight

$$M_{sw} = \int_{r_{min}}^{R} m(r) g (r - r_{min}) dr \qquad (20)$$

Where *m(r)* is the mass of the blade per unit length. This is a tangential (edge-wise) bending moment and therefore the maximum bending stress due to self-weight is given by:

$$\sigma_{max,sw} = \frac{M_{sw}}{I_{NN}} \frac{b}{2} \qquad (21)$$

- Combined Loading

$$\sigma_{max} = \sigma_{max,aero} + \sigma_c + \sigma_{max,sw} \qquad (22)$$

III. CHARACTERISATION OF THE CELLULOSE FIBERS

The cellulose long or woven fibers, fig.4 could be extracted from several types of natural materials such as Alpha [5], wood, palm, Flax, Hemp [6] etc.

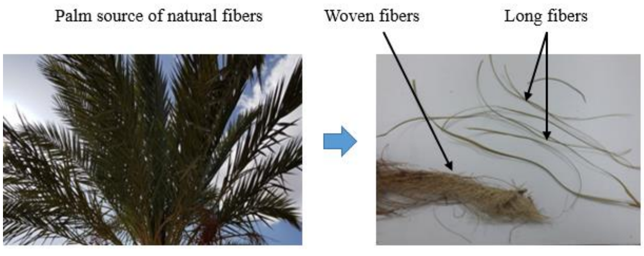

Fig. 4 Cellulosic source of natural fibers: long and woven fibers

According to the work of Murali Rao et al. [6] and Mark C. Symington et al [7] the estimate cross-section of cellulose fiber

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Vol.38 pp.80-85

was carried out using a digital micrometer. And according to Mark C. Symington et al [7] due to the potential variability in natural fiber properties, 25 tests per fiber might help to increase the quality of approximation. This was felt necessary due to the errors already associated with measuring the cross-sectional areas. For the tensile testing of cellulose natural fiber, the closest applicable standard used was ASTM D 3822 [8].
The mechanical behavior of some ordinary fibers and cellulose fibers was collected and then compared and verified based to literature. In the table 2 various mechanical properties of the different standard fibers materials used in turbine blade construction are tabulated.

TABLE II

MECHANICAL BEHAVIOR OF COMMON SYNTHETIC FIBERS USED IN TURBINE BLADE AND NATURAL FIBERS

Type of fibers	Designation	Young Modulus (GPA)	Tensile strength (MPA)	Density (g/cm^3)	Tensile strain to failure (%)
Synthetic Fibers [9]	Glass – E	73	3500	2.54	3
	Carbon	350	4000	1.75	1.8
	Aramid	120	3600	1.45	11
Natural Fibers [10-14]	Abaca	12	764	6.2	2.6
	Bagasse	17	290	-	-
	Bamboo	11	140	0.6-1.1	-
	Flax	54	1339	1.5	3.27
	Hemp	70	900	1.47	1.6
	Jute	20	533	1.3	1.2
	Kenaf	53	930	1.45	1.6
	Sisal	9	568	1.5	3
	Ramie	24.5	560	1.5	2.5
	Oil palm	3.2	248	0.7-1.55	25
	Pineapple	1.44	400	0.8-1.6	14.5
	Coir	6	175	1.2	30
	Curaua	11.8	500	1.4	3.7-4.3
	Alpha	18-25	188-308	1.4	1.5-2.4

Based to the results gathering in the table 2, it is reassuring to see that most of the behaviors of natural fibers are so much feeble comparing with the synthetics fibers.
From the literature of the tensile tests it is see that the mechanical behavior could be affected by the humidity and it may be necessary to investigate that cause more deeply in next steps of this research work.
The Hemp and flax fiber there are the most resistant fibers compared with other types and they could bring a good resistance to the wind blade.

IV. THE AEROFOIL SELECTION AND THE FEM OF THE BLADE SUCTION

The Aerofoil of the wind turbine blade was designed under Abaqus software. The composite material structures was defined as shown in table 1 with long and woven fabric fibers. The finite element model of the blade was established based to a simple Procedure for calculation and choosing of blade shape, see fig. 8. The composite structure was selected as Resin Epoxy for the matrix and five different fibers selected from table n2. The structure was first selected as a part of the whole blade and based to the loading and boundary conditions a CFD simulation was conducted to observe the wind velocity effect on the top surface of the blade see fig.6. The Von Mises results of Aerfoil made from a composite cellulosic natural fibers (Hemp)/ Resin Epoxy is shown in fig. 7. Through the analysis of the wind turbine blade and via solving the combined stress (equation 22), it can be seen that the biggest stress occurs in the center of the blade and in the joint parts. The maximum stress on the Aerofoil is less than the tensile strength of the natural fiber reinforced Resin epoxy that is mean the NFC based to cellulosic fibers could support the combined stress that related to wind turbine blades.

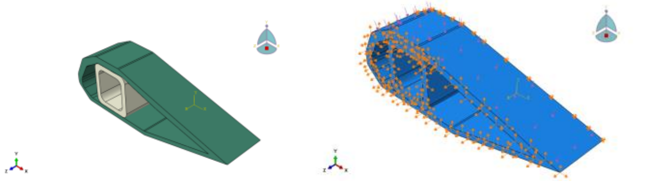

Fig. 5 Model and boundary condition

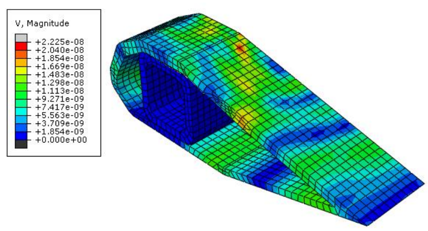

Fig. 6 CFD results on Arefoil wind turbine blade

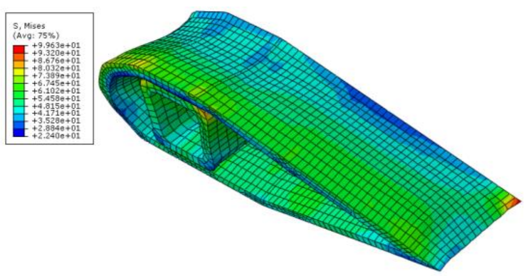

Fig. 7 Von Mises results on Wind Turbine blade made from NFC (Hemp fibres' reinforcement)

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Proceedings of Engineering and Technology – PET
Vol.38 pp.80-85

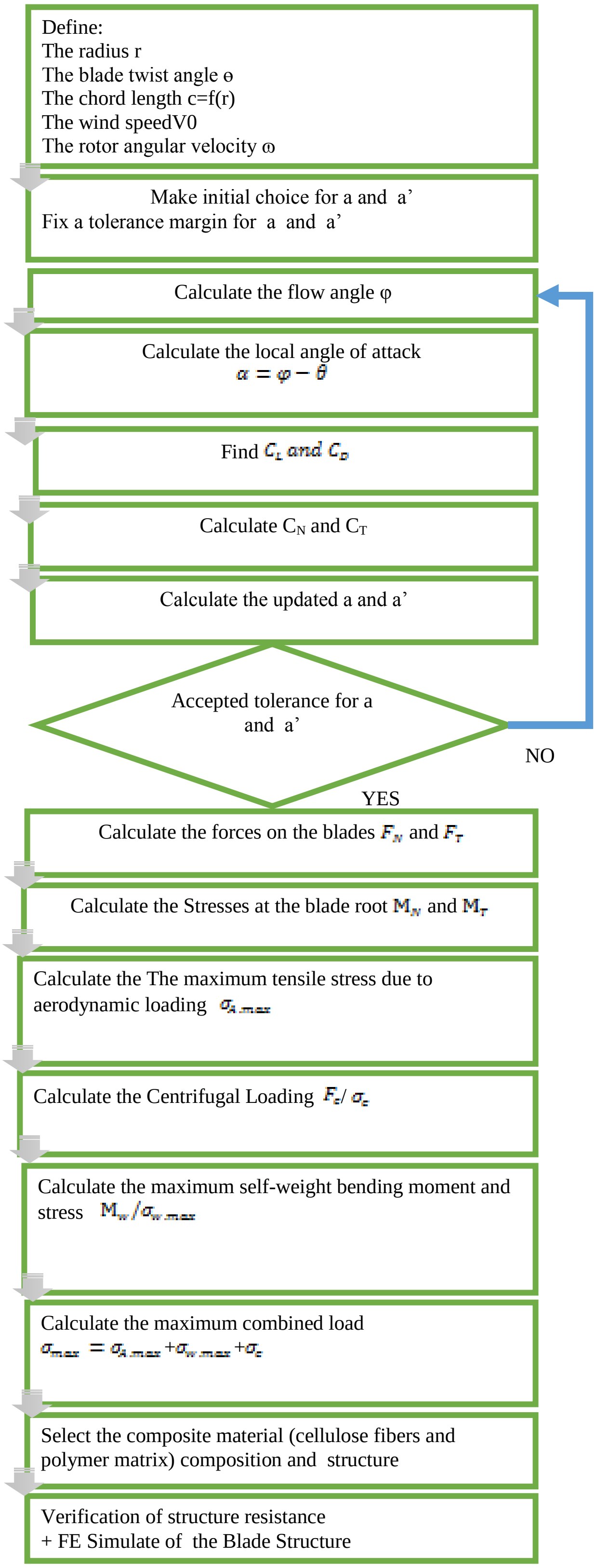

Fig. 8 Procedure for choosing the wind turbine blade parameters and FE verification of the structure resistance

The fig.9 illustrate the FE results of the resistance of the wind turbine blade structure to the combined loading through several fibers sources. By fixing the same boundary conditions and applied forces. It was observed that the change of fibers types brings a remarkable change in resistance of wind turbine blade. It is concluded that uses of Hemp or Alpha fibers in the structure of wind turbine blades brings a suitable resistance to the complex loading, see fig. 9.

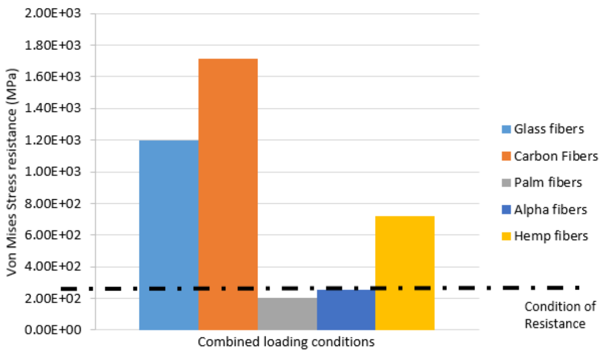

Fig. 9 Von Mises results of wind turbine blade's composites at different reinforcement fibers sources under combined loading

V. Conclusion

In this work the analysis of stress in wind turbine blade was carried out, then the performance of some natural fibers was gathering. Based on the literature tensile testing carried out in different types of fibers and based on the present developed FEM the mechanical behavior of the wind turbine blade were obtained for natural and synthetic composite fibers under combined stress condition. The present FE simulation offer an essential method for comparing the level of wind stress resistance of WTB made from natural fiber sources or ordinary synthetic fibers. It was observed that some natural fibers could give a competitive mechanical behavior and good resistance of the wind turbine blade to the combined loading stresses. The uses of cellulosic fibers such as Hemp and Alpha fibers as reinforcement of the structure of wind turbine blades brings a suitable resistance to the complex loading and sustainable environmental influence throughout achieving an efficient waste management practice. To confirm the reliability of the present investigation a future experimental work of the NFC wind turbine blade resistance to combined loading conditions is needed to be carried out.

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